Seismic Ground Motions for the Delta Levees

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Summary

The Delta Levees are located in a region of relatively low seismic activity as compared to the San Francisco Bay area. For the western islands, the most important seismic sources for a return period of about 100 years are the blind thrusts faults and the background earthquakes (random earthquakes occurring off of known faults). For the eastern islands, the distant San Andreas and Hayward faults become significant contributors to the hazard in addition to the blind thrusts and background earthquakes.

There is large uncertainty in the blind thrust faults in the Delta region. Because of this large uncertainty, two alternative models are considered. The first model is based on an extension of the Coast Range - Central Valley (CRCV) thrust faults into the Delta region. These blind thrust faults exist north and south of the delta along the western boundary of the central valley, and in this model they are assumed to extend through the delta.

The second model is based on recent geologic studies that suggest that the CRCV thrust faults do not extend into the delta region. Instead, thrust faults located further west of the delta are postulated.

Although the models are quite different, they produce similar levels of ground motion in the delta region using a probabilistic analysis. For the top of stiff soils, the 100 year horizontal peak acceleration ranges from 0.2 g in the western islands to 0.1 g in the northeastern islands.

For the western islands, the dominant earthquake contributing to the 100 year ground motion is a magnitude 5.8 - 6.2 earthquake at a distance of about 25 km. For the eastern islands, the magnitude 7.5-8.0 events on the San Andreas fault and magnitude 7 events on the Hayward fault also contribute significantly to the hazard, in addition to the magnitude 5.5 - 6.0 event on the background zone. The mean magnitude contributing to the 100 year return period hazard for the eastern Islands is about magnitude 6.

Since the hazard is dominated by moderate magnitude local events, it is unlikely that the entire delta will be subject to the 100 year ground motion in a single 100 year earthquake.

Introduction

The Delta Levees are located in a region of relatively low seismic activity. However, there is a large earthquake (M 6.5 - 7) on a local fault in the delta region, then there will large ground motions (exceeding 0.2 g) at the western islands. Although a large local event cannot be ruled out, it has a low probability of occurring. Probabilistic seismic hazard analysis is a method that explicitly considers how often earthquakes of various sizes will occur and what is the likely ground motion that will occur if an earthquake occurs. In this manner, it allows an evaluation of the seismic risk of the levees.

The probabilistic approach used in this study follows the standard approach first developed by Cornell (1968) with some modifications to more fully address all sources of variability.

There are three main parts of the variability that are considered in a seismic hazard analysis: what are the magnitudes of the earthquakes, where are the earthquakes located, and what is the ground motion given that an earthquake of a specified magnitude has occurred at a specified location.

The source characterization described the rate of earthquake as well as the distribution of magnitudes and locations. The attenuation relation describes how strong the ground shaking will be for a given magnitude and location. These components of the hazard analysis are briefly described below. The resulting horizontal peak acceleration hazard is then discussed.

Descriptions of Seismic Sources

The faults considered in the hazard analysis are shown in Figure 1a and 1b, for the two alternative models of the delta thrust faults considered in this study. The mean slip-rate, fault width, and maximum magnitude of the faults are listed in Table 1. The main strike-slip faults in the Bay area (San Andreas, Hayward, Calaveras) contribute to the hazard in the delta for short return periods.

In addition to the faults, a background source zone is also included to capture the earthquakes to occur off of known faults. The background zone is based on the

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smoothed historical seismicity (M≥4.0) developed by USGS (1996) and used by the CDMG in the state hazard maps. This background seismicity is smoothed over a distance of 50 km, resulting in very smooth background seismicity. The rate of magnitude 5 or greater earthquakes per 100 years per 100 square km is shown in Figure 1c. To avoid double counting seismicity, the background zone is used for magnitudes 5-6 and the faults are used for magnitudes greater than 6.0.

The two alternatives for the thrust faults are discussed in more detail below.

Delta Region Thrust Faults

Geodetic data indicates that there crustal shortening in the direction normal to the San Andreas fault between the Pacific Plate and the North American Plate of about 3 mm/yr. The primarily strike-slip earthquakes in the Bay Area region accommodate some of this shortening, but some thrust faults are needed to explain the remainder of the shortening between the Pacific and North American plates in this region. The thrust faults generally does not reach the surface and are considered a "blind thrust" faults.

In most recent studies, most of the additional shortening has been accommodated along the western edge of the central valley, called the Coast Range/Central Valley Thrust (CRCV) fault zone (also called the Coast Range Sierran Block Boundary Zone).

There have been several earthquakes over magnitude 6 that have occurred along the CRCV fault zone. The 1983 Coalinga earthquake (M=6.4) and the 1985 Kettleman Hills earthquake (M=6.1) occurred on the CRCV. The 1892 Winters- Vaccaville earthquake (M=6.4) may also have occurred on the CRCV, but its location is not well constrained (Toppozada, Real, and Parke, 1981). The CRCV is clearly an active fault in some regions, but it may not exist in the Delta region.

In this evaluation, we consider two alternative models of the thrust faults in the delta region which we call the CRCV model and the Lettis and Associates model. These two alternative models are discussed below.

CRCV Thrust Fault Model

The CRCV extends about 600 km along the western edge of the Central Valley in central and Northern California (Wong et al., 1988), but the faulting is discontinuous. Most of the segment lengths are 5 to 20 km with a maximum segment length of about 50 km . In

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the CRCV model, this set of thrust faults extends through the Delta region and runs near Sherman Island (Figure 1b).

The CRCV model has been used in the state hazard maps developed by the California Division of Mines and Geology (CDMG). The slip-rate of the CRCV in the delta region is uncertain. We have used a range of slip-rates from 0.5 to 3.0 mm/yr. The CDMG (1996) used a slip-rate of 1.5 mm/yr and that is the mean value that is used in this study.

The exact location of the CRCV fault in the delta region is uncertain. In this study, the top of the fault is located at a depth of 8 km with a dip of _ degrees. For a down-dip fault width of 15 km and a segment length of 40 km, the Wells and Coppersmith (1994) magnitude fault area relation gives a mean maximum magnitude of 6.8.

Lettis and Associates Model
A recent study by Unruh (Lettis and Associates written comm., 1998) suggests that the CRCV is not present in the Delta region. According this model, the CRCV begins to decrease in activity north of the San Luis Reservoir and south of Lake Berryessa. In the Delta region, the CRCV ceases to exist. As an alternative to the CRCV, the Lettis and Associates model postulates a different set of thrust faults further to the west (Figure 1a) to accommodate the crustal shortening.

The Pittsburg/Kirby Hills, Roe Island, Los Medanos, and Mount Diablo faults are all short faults with lengths of less than 20 km located 10-20 km west of the western Islands. The mean slip-rates of these faults range from 0.3 to 2 mm/yr. The maximum magnitudes of the small thrust faults range from 6.0 to 6.6.

This model also includes the Midland fault located under the delta but with a small mean slip-rate of 0.15 mm/yr. Although the Midland fault has a length of about 60 km, the maximum magnitude of the Midland fault given in this model is only 6.2.

Attenuation Relations
There are many attenuation relations that can be used for the deep soil site condition (below the peat) in the delta. In this study, we have selected four of the most recent

attenuation models: Abrahamson and Silva (1997), Boore et al (1997), Campbell (1997), and Sadigh et al (1997). These models are given equal weight in the hazard analysis.

Probabilistic Hazard Results

The probabilistic hazard is shown separately for the Lettis model and the CRCV models of the delta thrust faults. The results for the Lettis model are shown first, and the results for the CRCV model are shown second. Sherman Island and Terminous Island are used as examples representative of the western islands and eastern islands, respectively.

Figure 2a-b show the peak acceleration hazard for Sherman Island and Terminous Island, respectively. At a return period of 100 years (annual probability of 0.01), the hazard at Sherman Island is dominated by the thrust faults, with significant contribution from the background zone and "other" faults. For Terminous Island, the background zone and thrust faults have similar contribution to the 100 year hazard.

The magnitude and distance of the earthquakes dominating the hazard can be estimated by deaggregating the hazard. The contribution to the hazard is shown in Figures 3a and 3b. For Sherman Island, the hazard is primarily from moderate magnitude events (M5.5-6.5) at distances of 10 to 30 km. For Terminous Island, the more distant sources also contribute to the hazard and there is a wide range of magnitudes and distances (M5-6 at 10-30 km to M7-7.5 at 100 km) contributing to the hazard. Figures 4a and 4b show the mean magnitude and mean distance of the earthquakes contributing to the hazard as a function of the return period.

A similar set of plots for the CRCV model is shown in Figures 5-7. The main difference is that for the CRCV model, the CRCV thrust faults are the controlling source for both Sherman Island and Terminous Island.

The hazard for the Lettis and CRCV models is compared in Figure 8. This figure shows that the hazard from these two models is very similar for both the Sherman Island and Terminous Island sites.

The two models are given equal weight in the final hazard analysis. Contours of the peak acceleration in the delta region for return period of 43 years, 100 years, 200 years,

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Table 1. Seismic source parameters.

Fault	Slip Rate (weights)	Fault Width (weights)	Max. Magnitude (weights)
Concord	3.0, 4.0, 6.0 (0.25,0.5,0.25)	12.0 (1.0)	6.4, 6.6, 6.8 (0.2,0.6,0.2)
Calaveras (North)	2.0, 6.0, 8.0 (0.25,0.5,0.25)	12.0 (1.0)	6.7 (1.0)
Calaveras (South)	13.0, 15.0, 17.0 (0.25,0.5,0.25)	12.0 (1.0)	6.8 (1.0)
Hayward	7.0, 9.0, 11.0 (0.25,0.5,0.25)	12.0 (1.0)	7.1 (1.0)
Marsh Creek/Greenville	0.5, 2.0, 3.0 (0.25,0.5,0.25)	12.0 (1.0)	6.7 (1.0)
Clayton	0.2, 0.5, 1.0 (0.25,0.5,0.25)	12.0 (1.0)	6.7 (1.0)
Green Valley	1.5, 4.0, 5.0 (0.2,0.6,0.2)	12.0 (1.0)	6.6 (1.0)
Napa	0.1, 0.3, 0.5 (0.3,0.5,0.2)	12.0 (1.0)	6.5 (1.0)
Rodgers Creek	6.0, 8.0, 11.0 (0.25,0.5,0.25)	12.0 (1.0)	7.0 (1.0)
San Andreas	19.0, 24.0, 29.0 (0.2,0.6,0.2)	15.0 (1.0)	7.8, 8.0 (0.8,0.2)
Verona	0.1 (1.0)	10.0 (1.0)	6.1 (1.0)
Antioch	0.3 (1.0)	15.0 (1.0)	6.5 (1.0)
Mt. Diablo Thrust[1]	1.3, 1.7, 5.0 (0.3,0.6,0.1)	11.0 (1.0)	6.25, 6.75 (0.30,0.70)
Los Medanos Thrust[1]	0.3, 0.7 (0.8,0.2)	13.0 (1.0)	6.00, 6.25 (0.8,0.2)
Roe Island Thrust[1]	0.1, 0.3, 0.7 (0.1,0.7,0.2)	14.0 (1.0)	5.75, 6.00 (0.5,0.5)
Potrero Hills Thrust[1]	0.1, 0.3, 0.6 (0.3,0.6,0.1)	14.25 (1.0)	6.00, 6.25 (0.8,0.2)
Pittsburg/Kirby Hills Thrust[1]	0.2, 0.3, 0.7 (0.5,0.4,0.1)	15.0 (1.0)	6.00, 6.50 (0.4,0.6)
Midland Thrust[1]	0.1, 0.2 (0.6,0.4)	13.0 (1.0)	6.00, 6.25 (0.7,0.3)
CRCV[2]	0.5, 1.5, 2.5 (0.25,0.5,0.25)	10.0 (1.0)	6.8 (1.0)

[1] Lettis source model for the Delta region.
[2] CRCV source model for the Delta region.
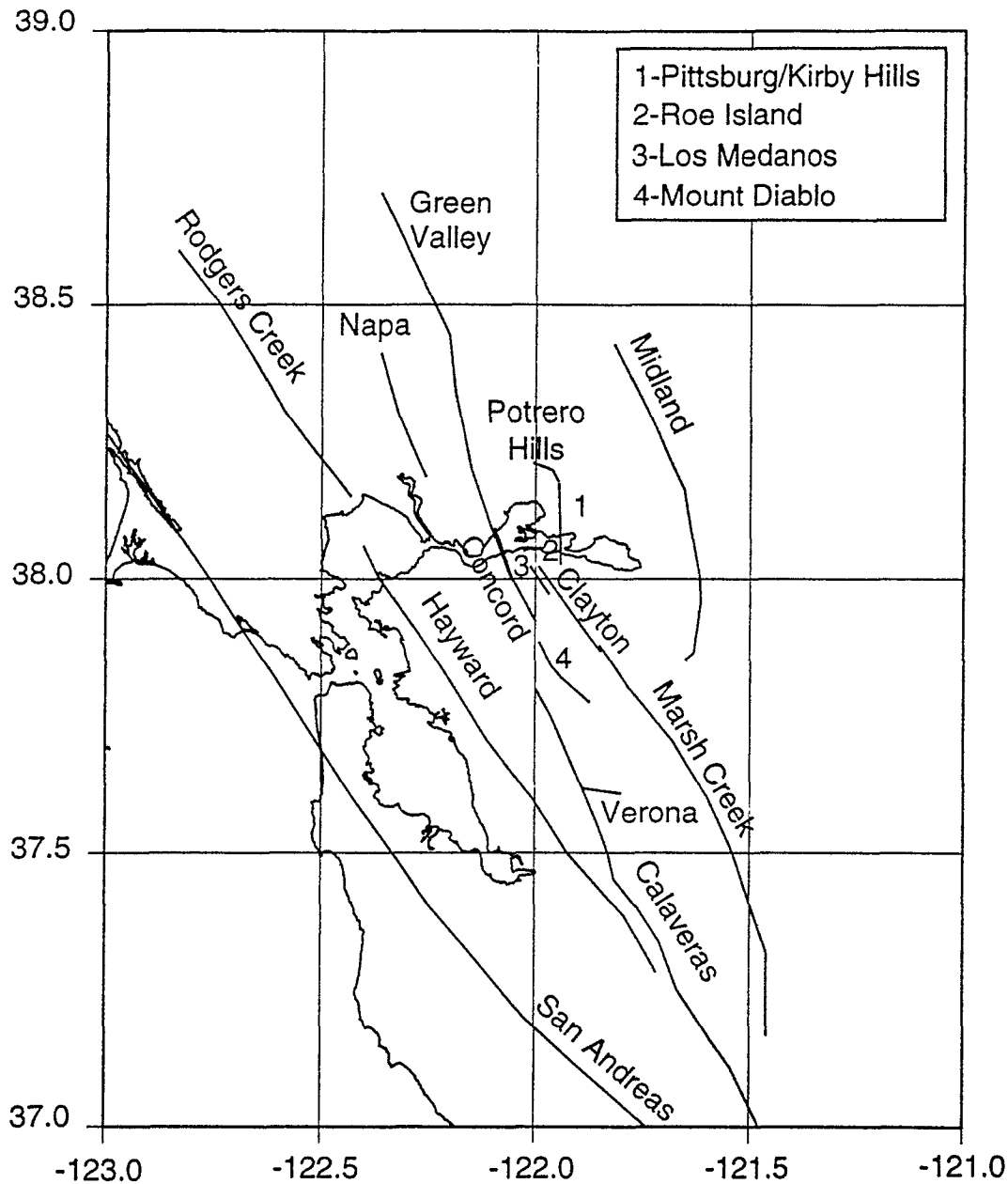
Figure 1a.   Map showing the significant faults in the Delta region used in the
seismic hazard computations based on the Lettis Delta fault model.
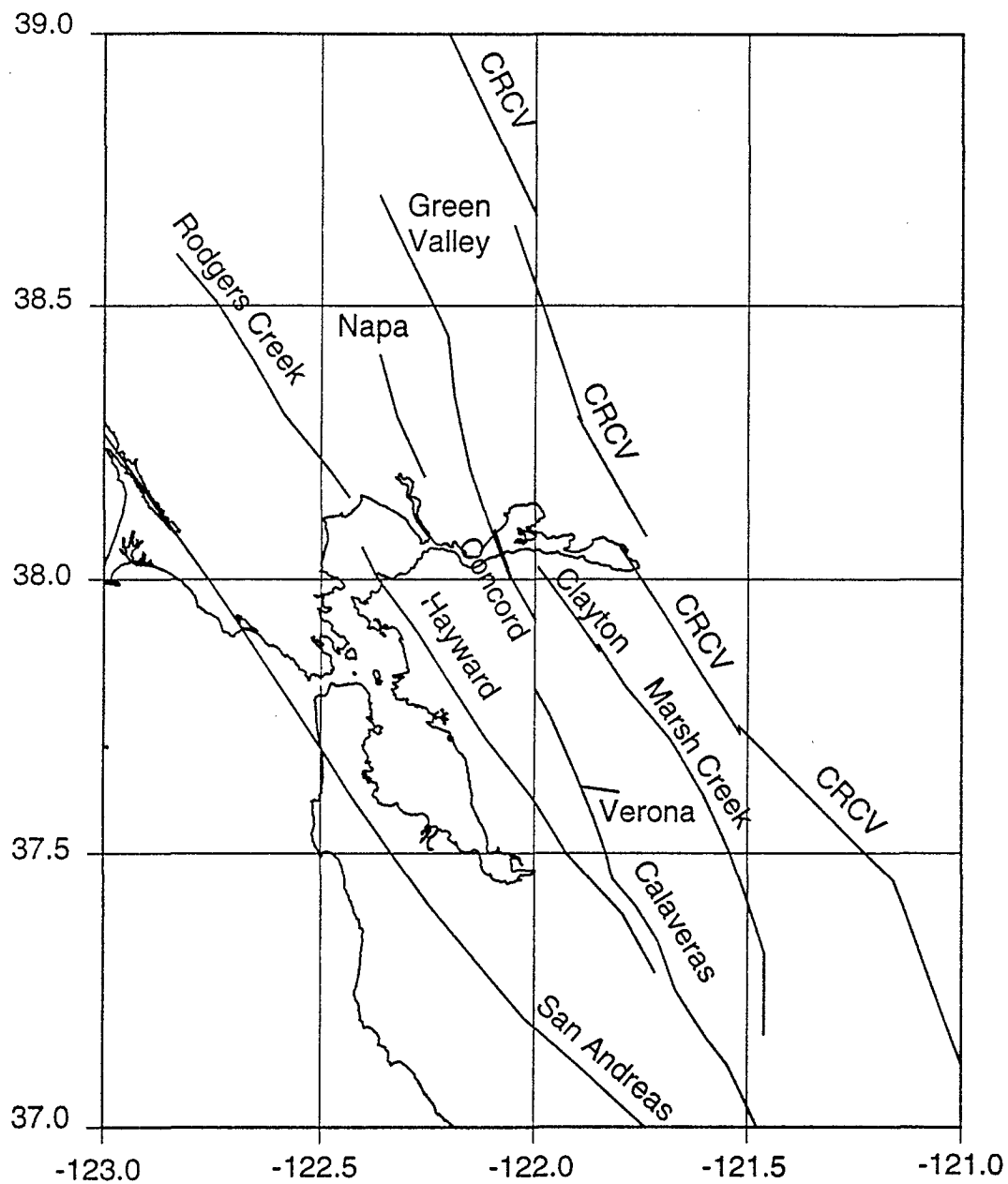
Figure 1b.   Map showing the significant faults in the Delta region used in the
             seismic hazard computations based on the CRCV Delta fault model.
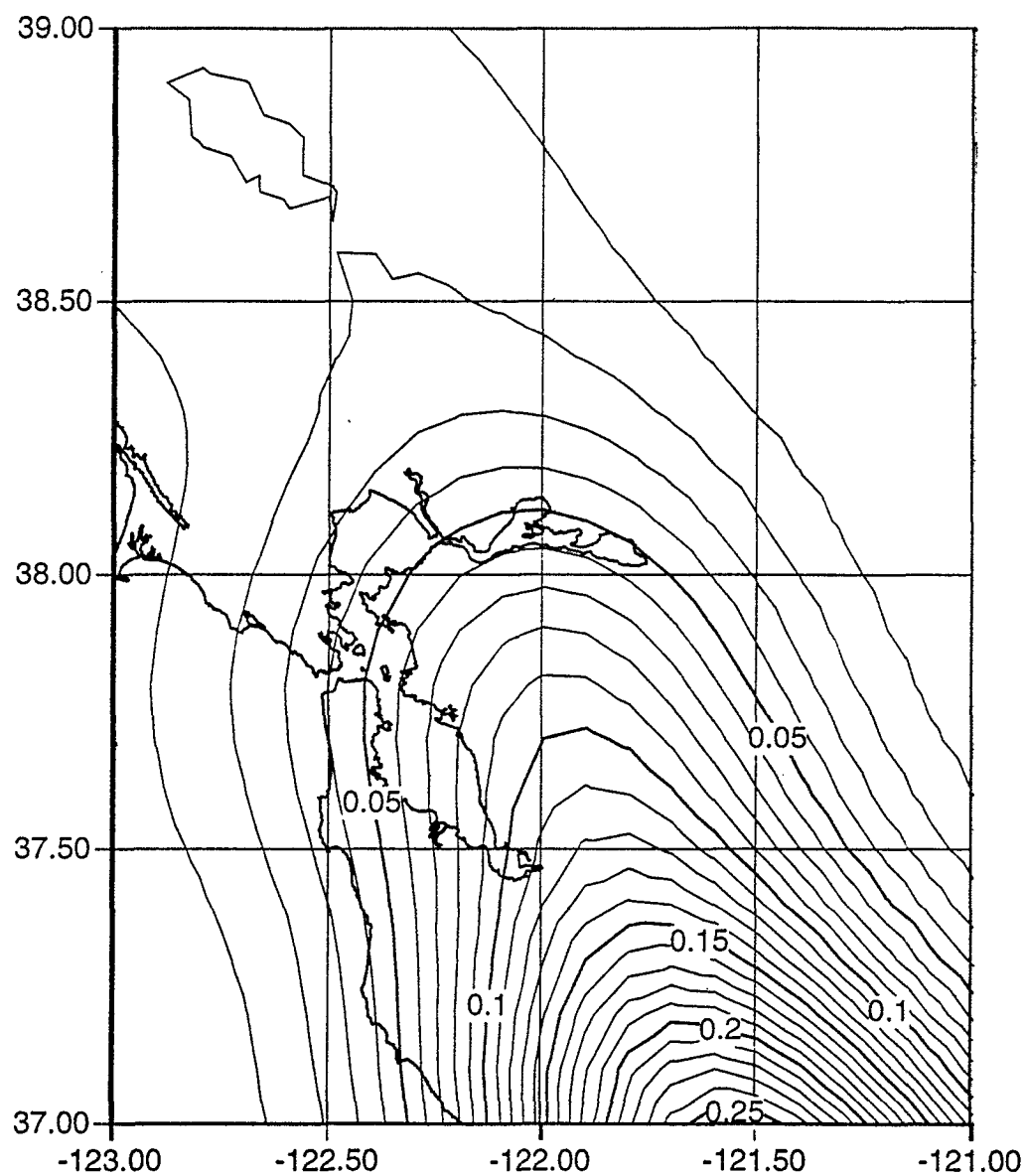
Figure 2c. Map showing the countour of smoothed background seismicity for magnitude 5.0 and greater per 100 years per 100 square kilometers. Based on the USGS gridded seismicity maps (1996).
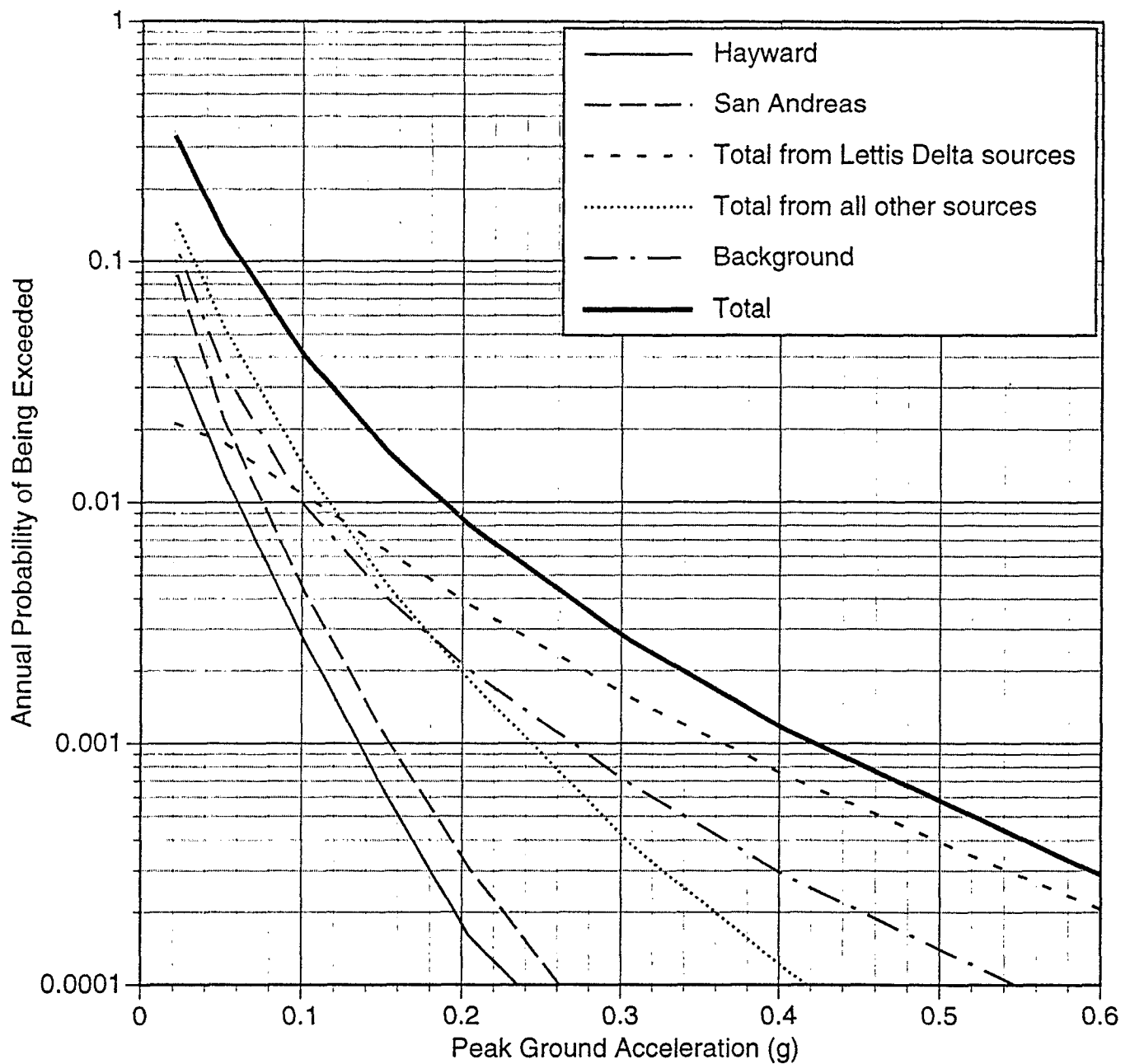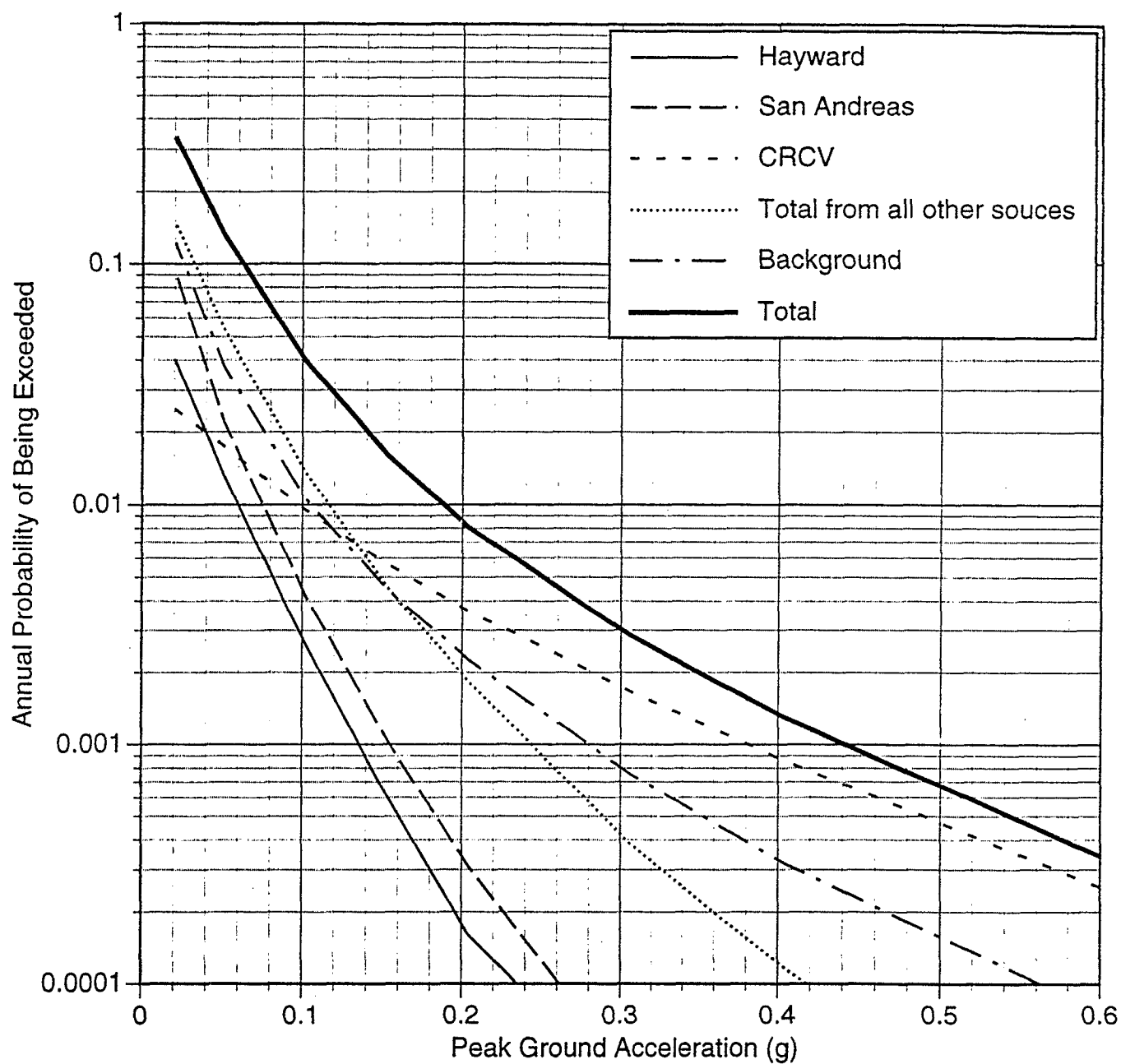
Figure 2a. Seismic hazard curves for the Sherman Island site. The hazard curves are based on the Lettis seismic source model for the Delta region. The contribution to the total hazard is shown for the significant faults.
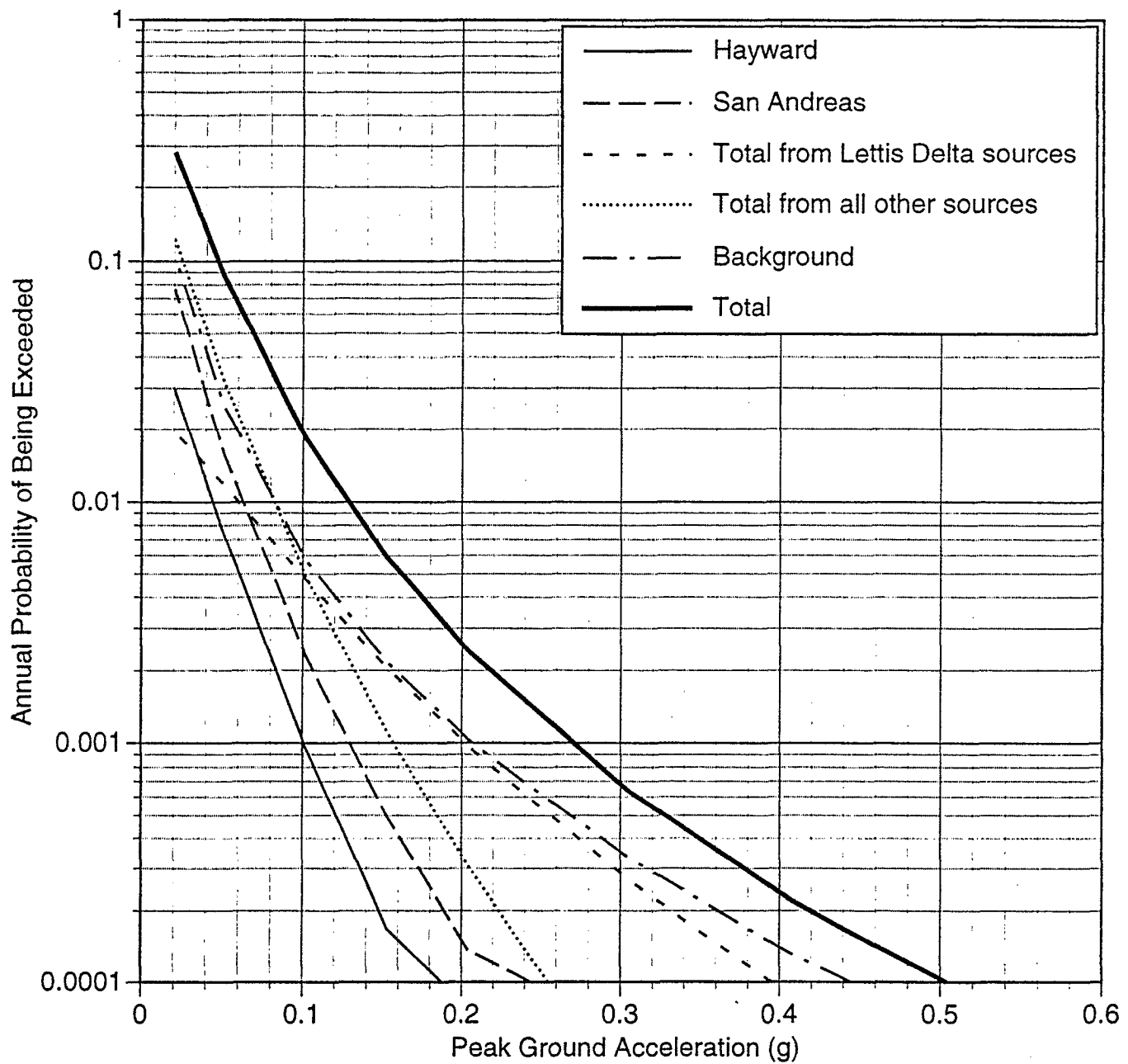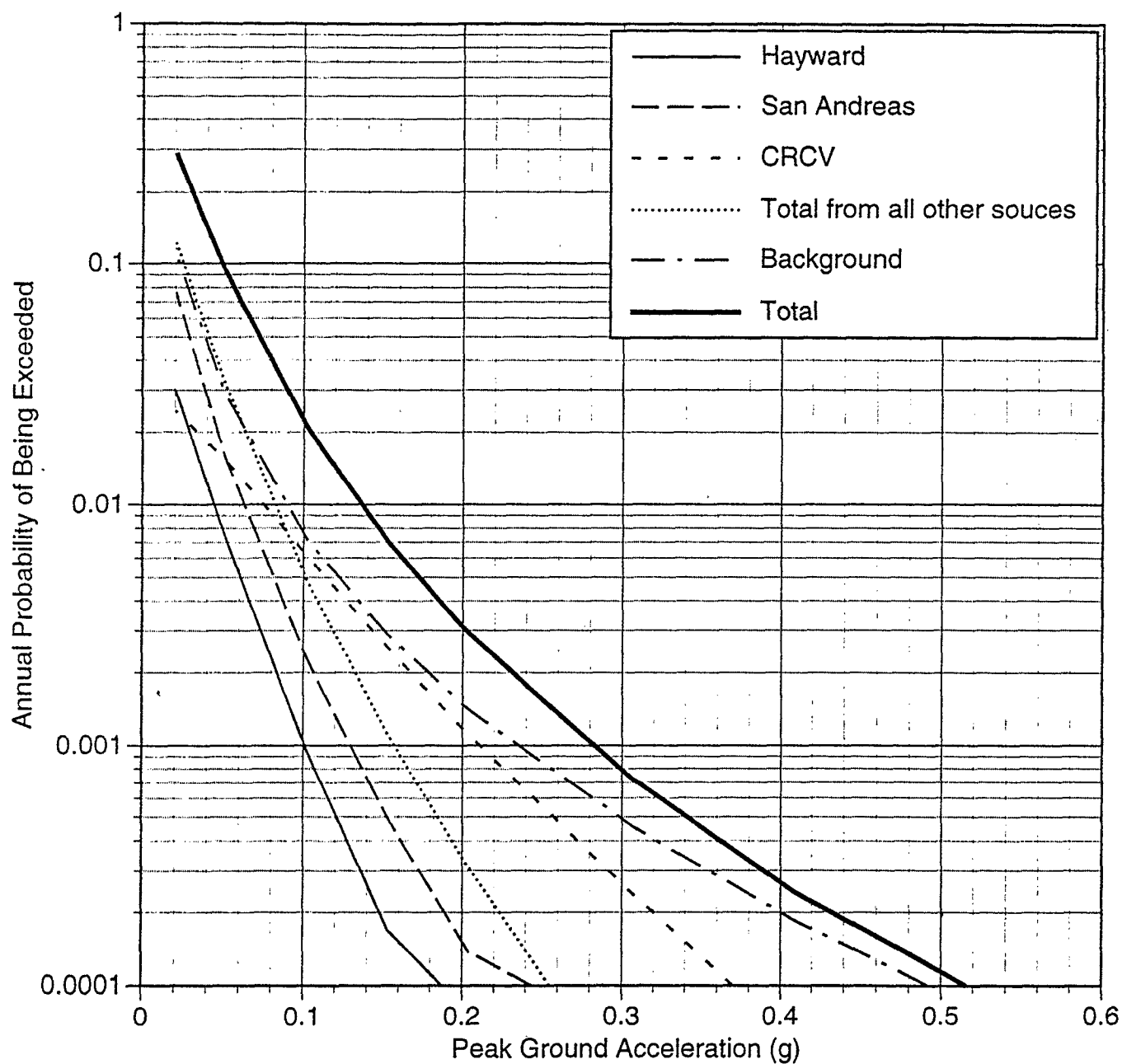
Figure 2b. Seismic hazard curves for the Terminous site. The hazard curves are based on the Lettis seismic source model for the Delta region. The contribution to the total hazard is shown for the significant faults.
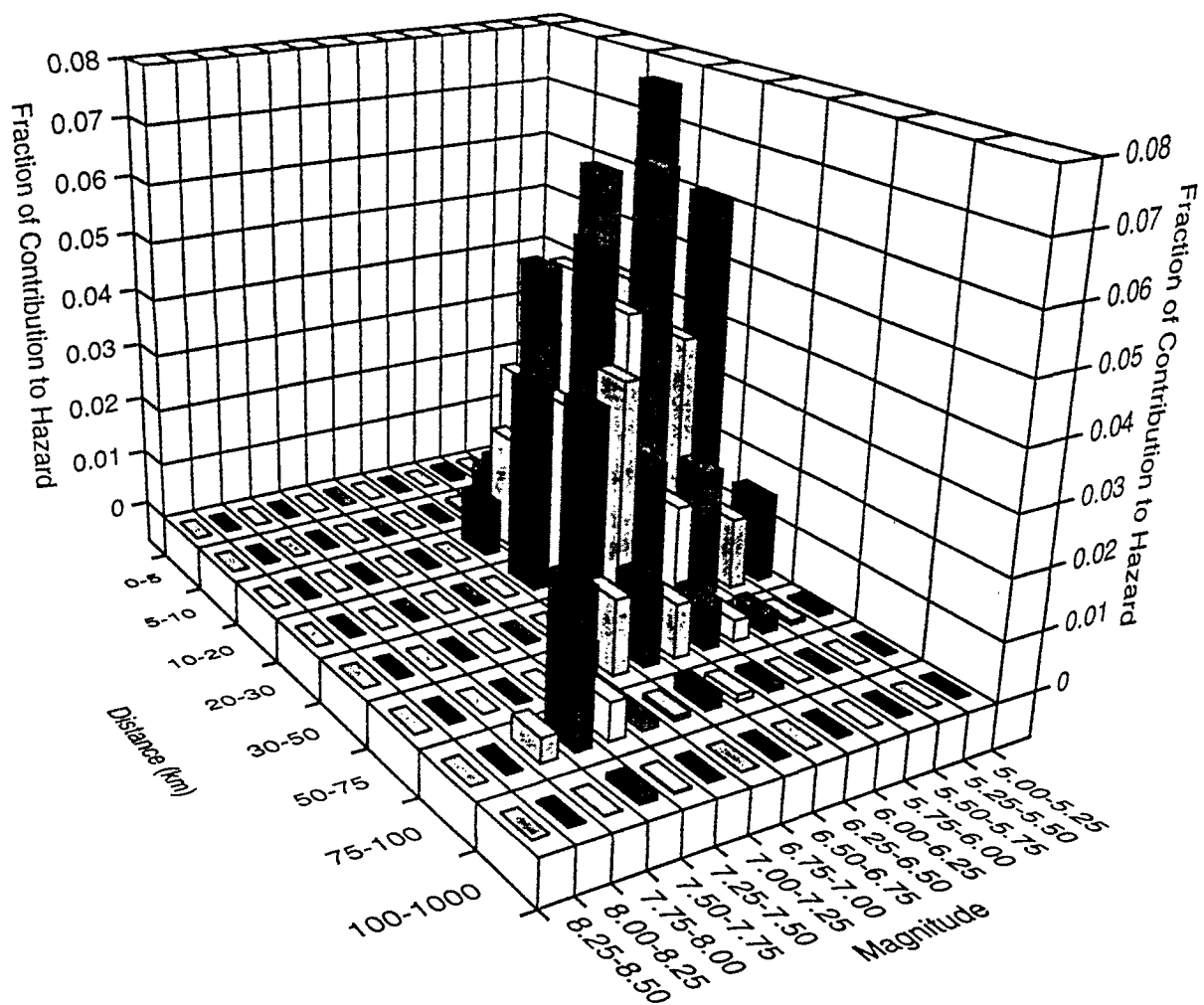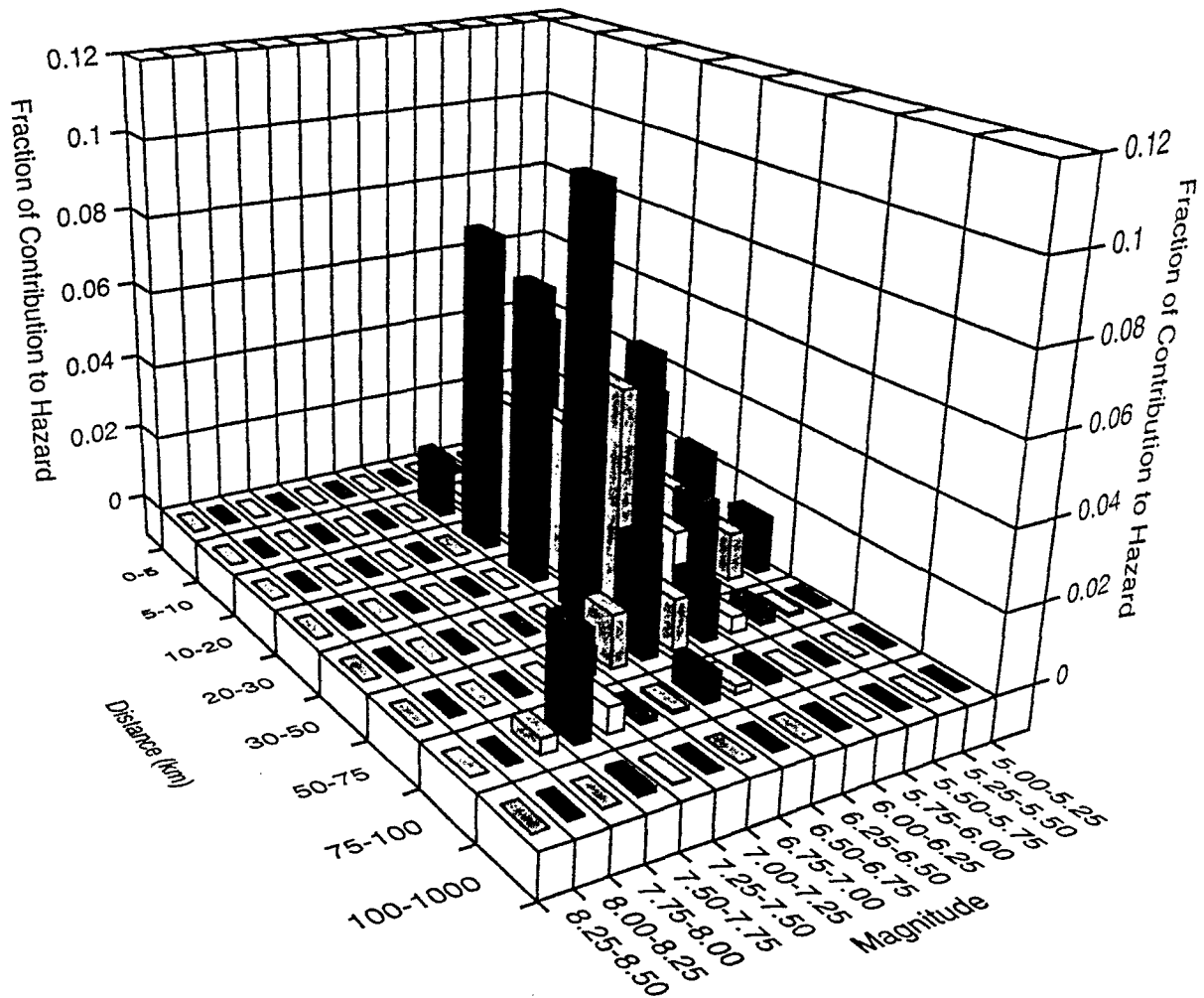
Figure 3a. Deaggregation of the seismic hazard (100 year return period) for the Sherman Island site based on the Lettis seismic source model for the Delta region.
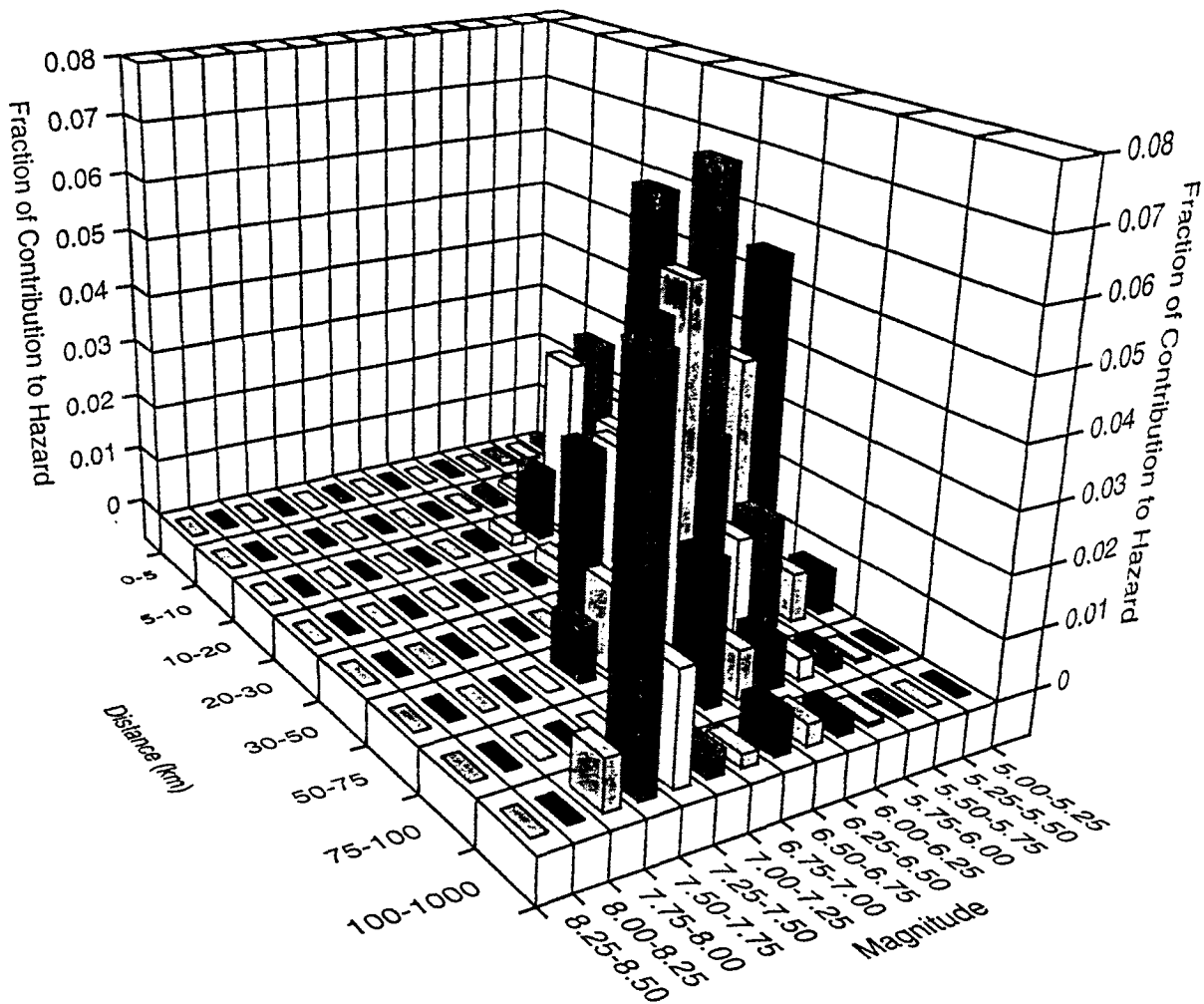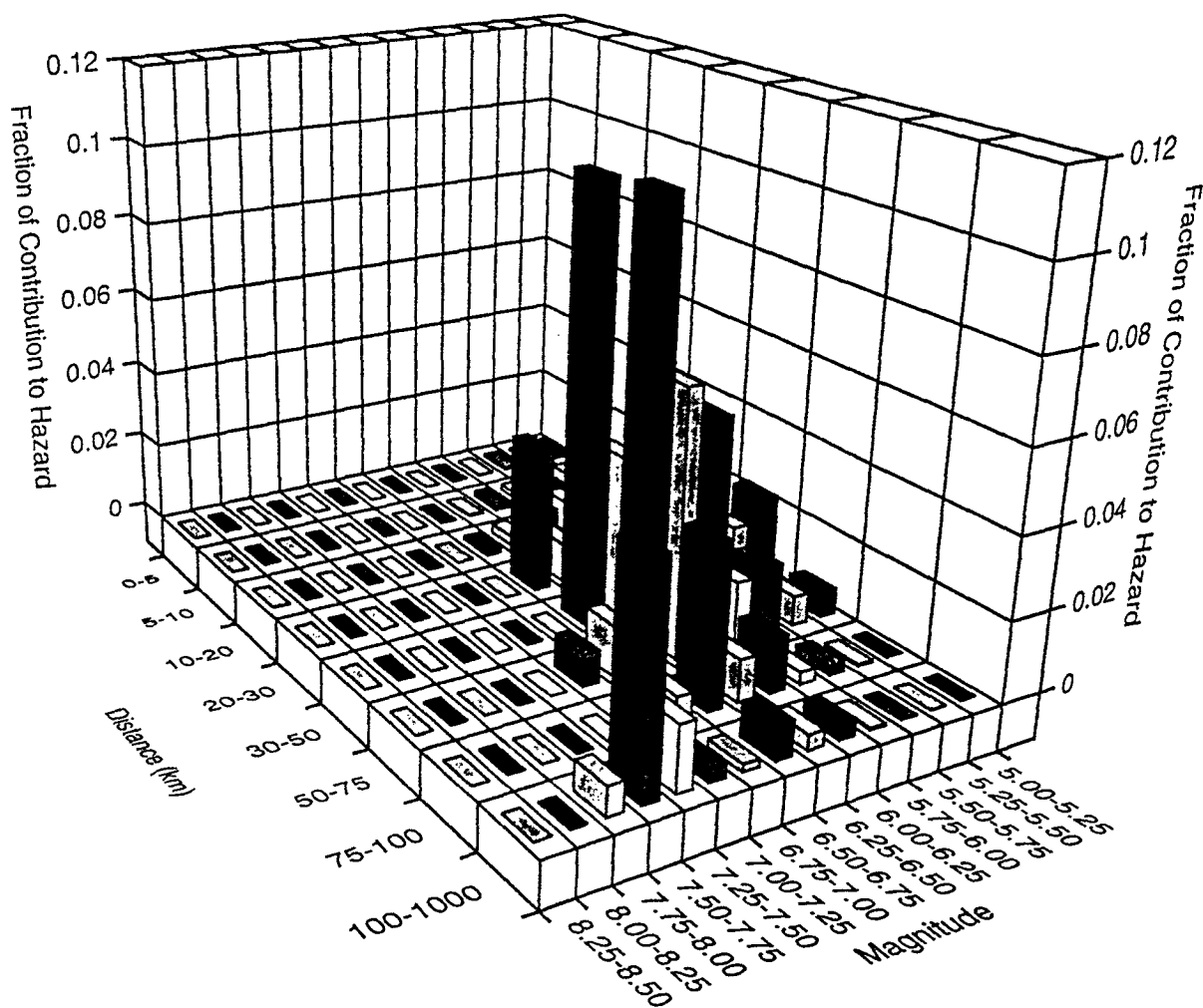
Figure 3b. Deaggregation of the seismic hazard (100 year return period) for the Terminous site based on the Lettis seismic source model for the Delta region.

Figure 4a. Magnitude, distance and epsilon bar for the Sherman Island site based on the Lettis seismic source model for the Delta region.
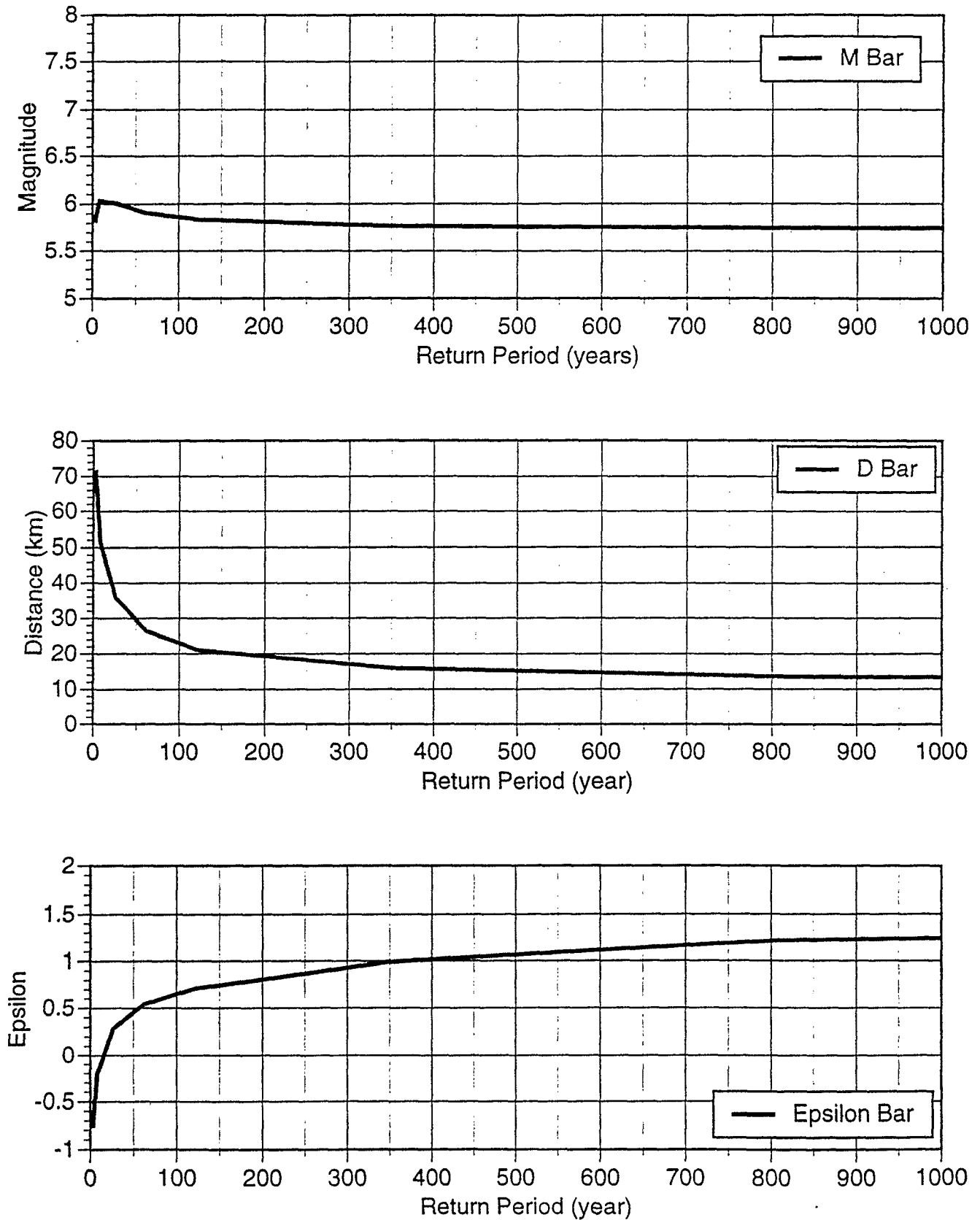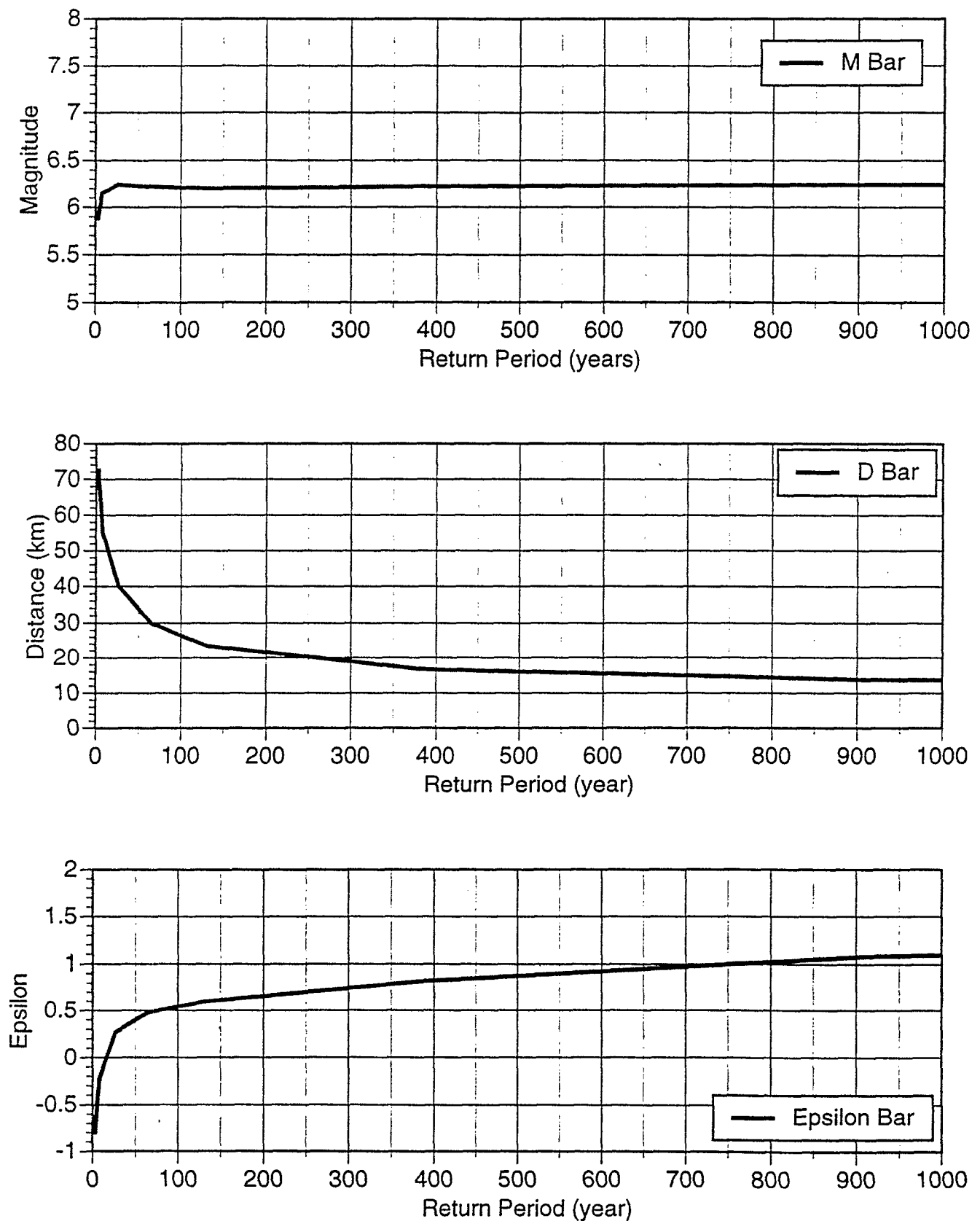
Figure 4b. Magnitude, distance and epsilon bar for the Terminous site based on the Lettis seismic source model for the Delta region.
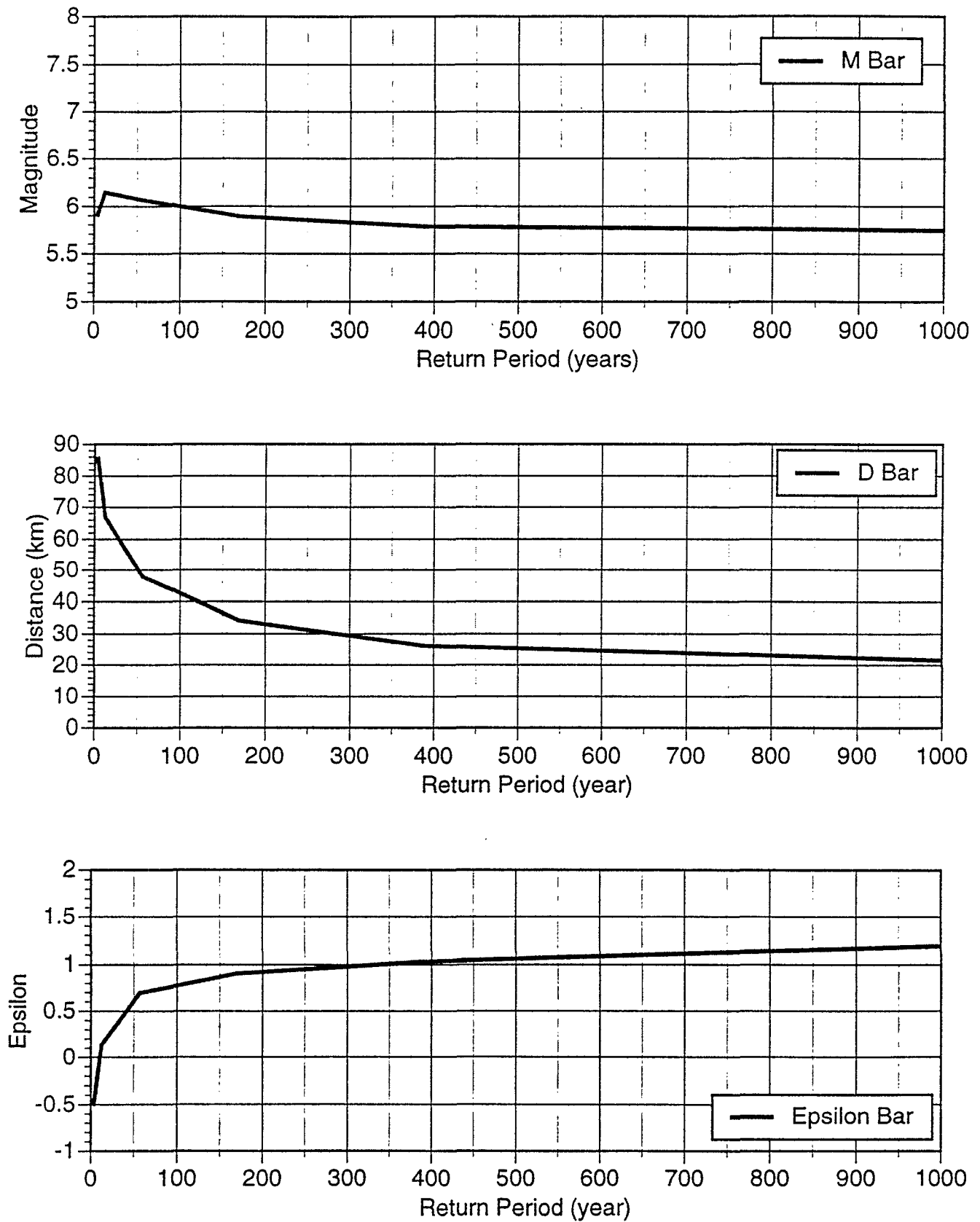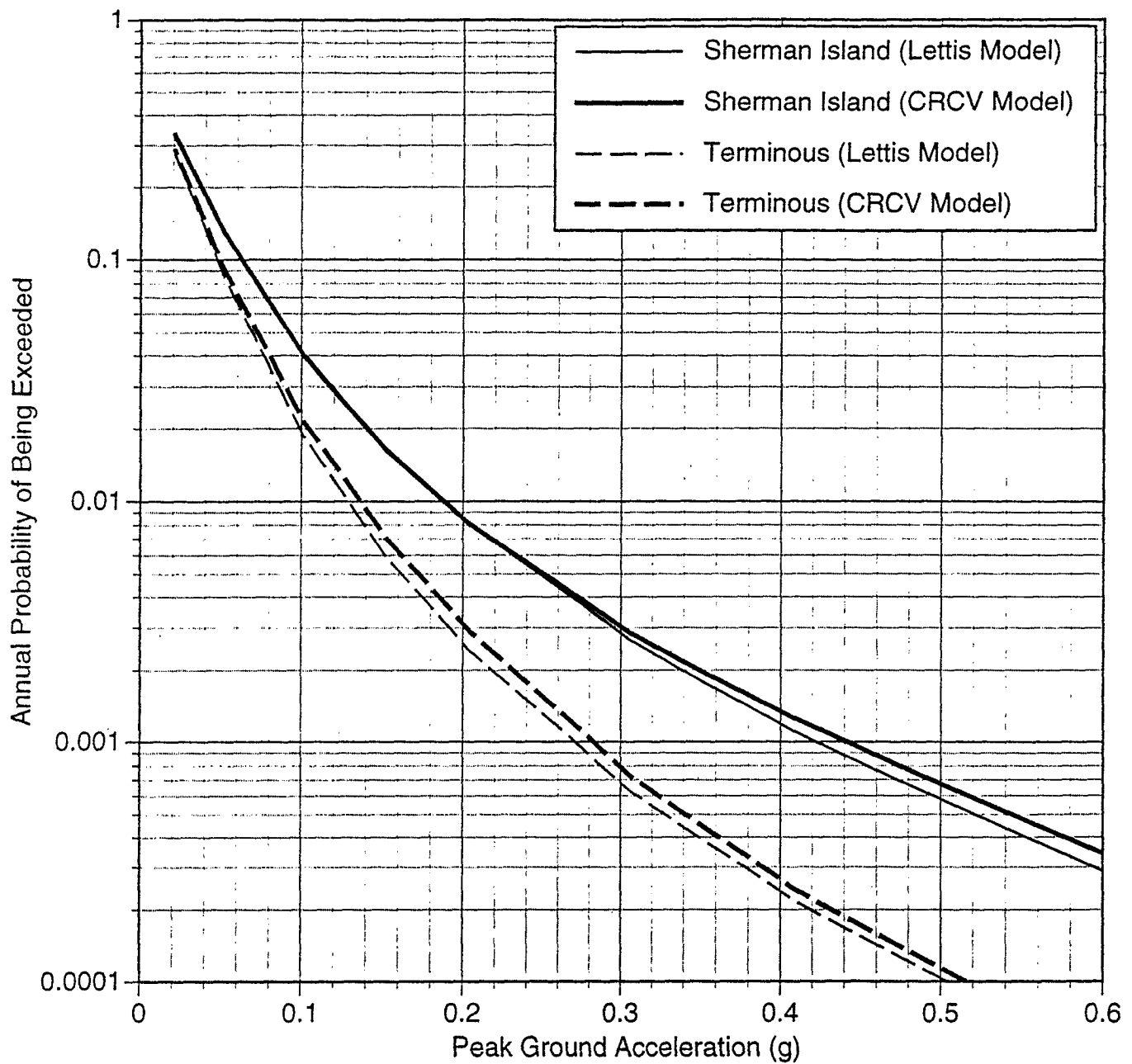
Figure 5a. Seismic hazard curves for the Sherman Island site. The hazard curves are based on the CRCV seismic source model for the Delta region. The contribution to the total hazard is shown for the significant faults.

Figure 5b. Seismic hazard curves for the Terminous site. The hazard curves are based on the CRCV seismic source model for the Delta region. The contribution to the total hazard is shown for the significant faults.

Figure 6a. Deaggregation of the seismic hazard (100 year return period) for the Sherman Island site based on the CRCV seismic source model for the Delta region.

Figure 6b. Deaggregation of the seismic hazard (100 year return period) for the Terminous site based on the CRCV seismic source model for the Delta region.

Figure 7a. Magnitude, distance and epsilon bar for the Sherman Island site based on the CRCV seismic source model for the Delta region.

Figure 7b. Magnitude, distance and epsilon bar for the Terminous site based on the CRCV seismic source model for the Delta region.
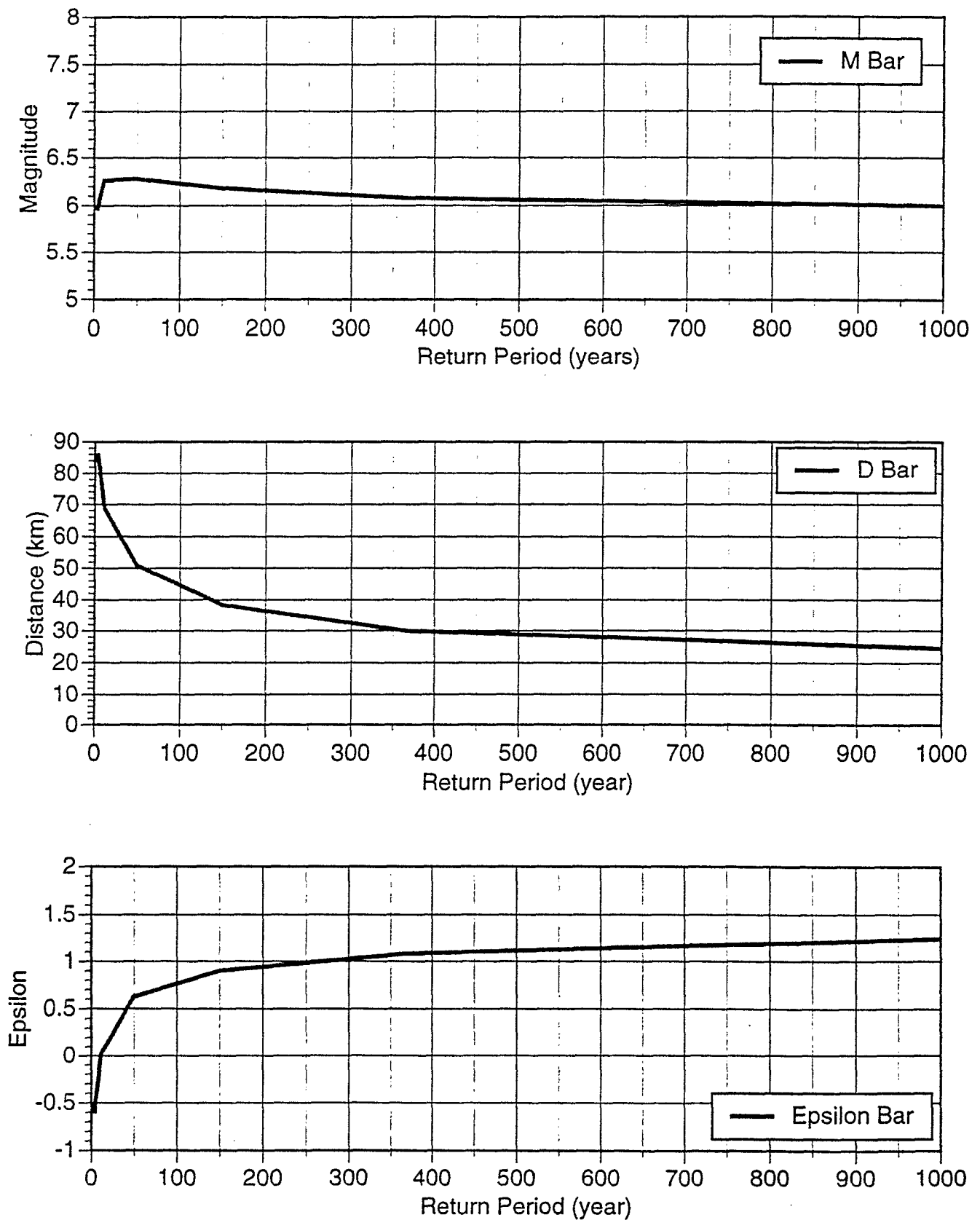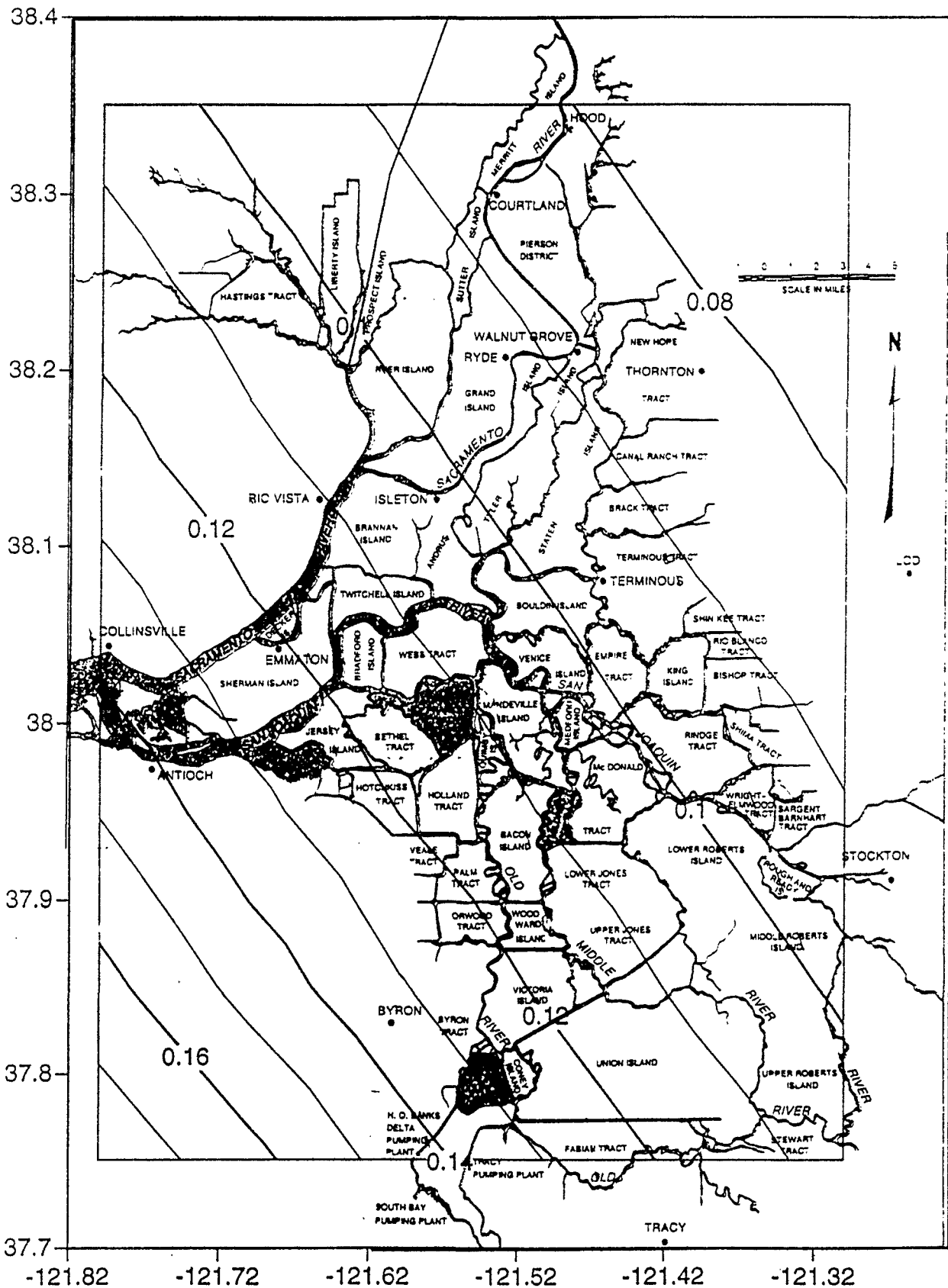
Figure 8. Comparison of the seismic hazard for the Sherman Island and Terminous sites based on both the Lettis and CRCV seismic source model for the Delta region.

Figure 9a. Contour map of seismic hazard (PGA) for soil site conditions for a return period of 43 years.

Figure 9b. Contour map of seismic hazard (PGA) for soil site conditions for a return period of 100 years.

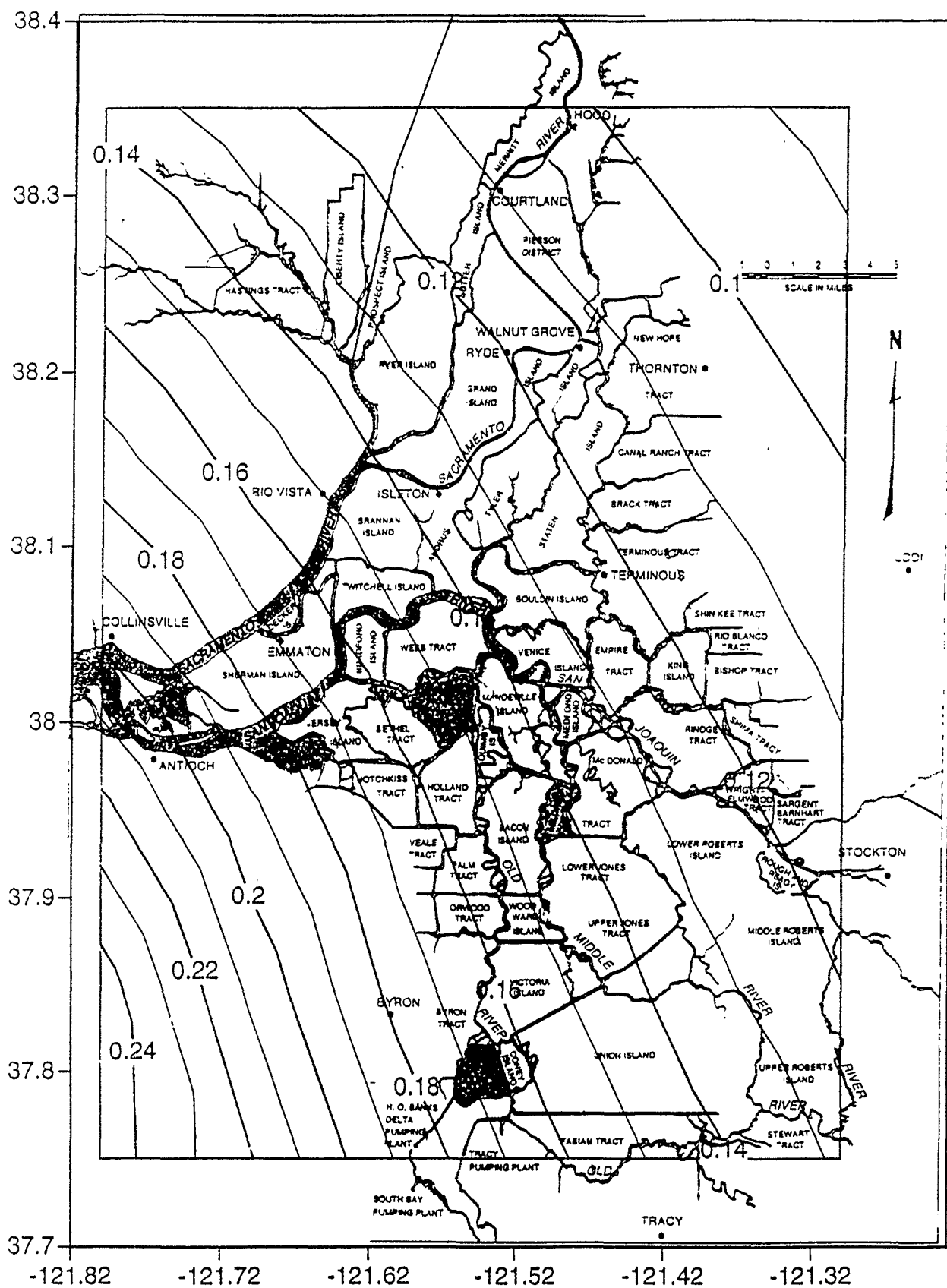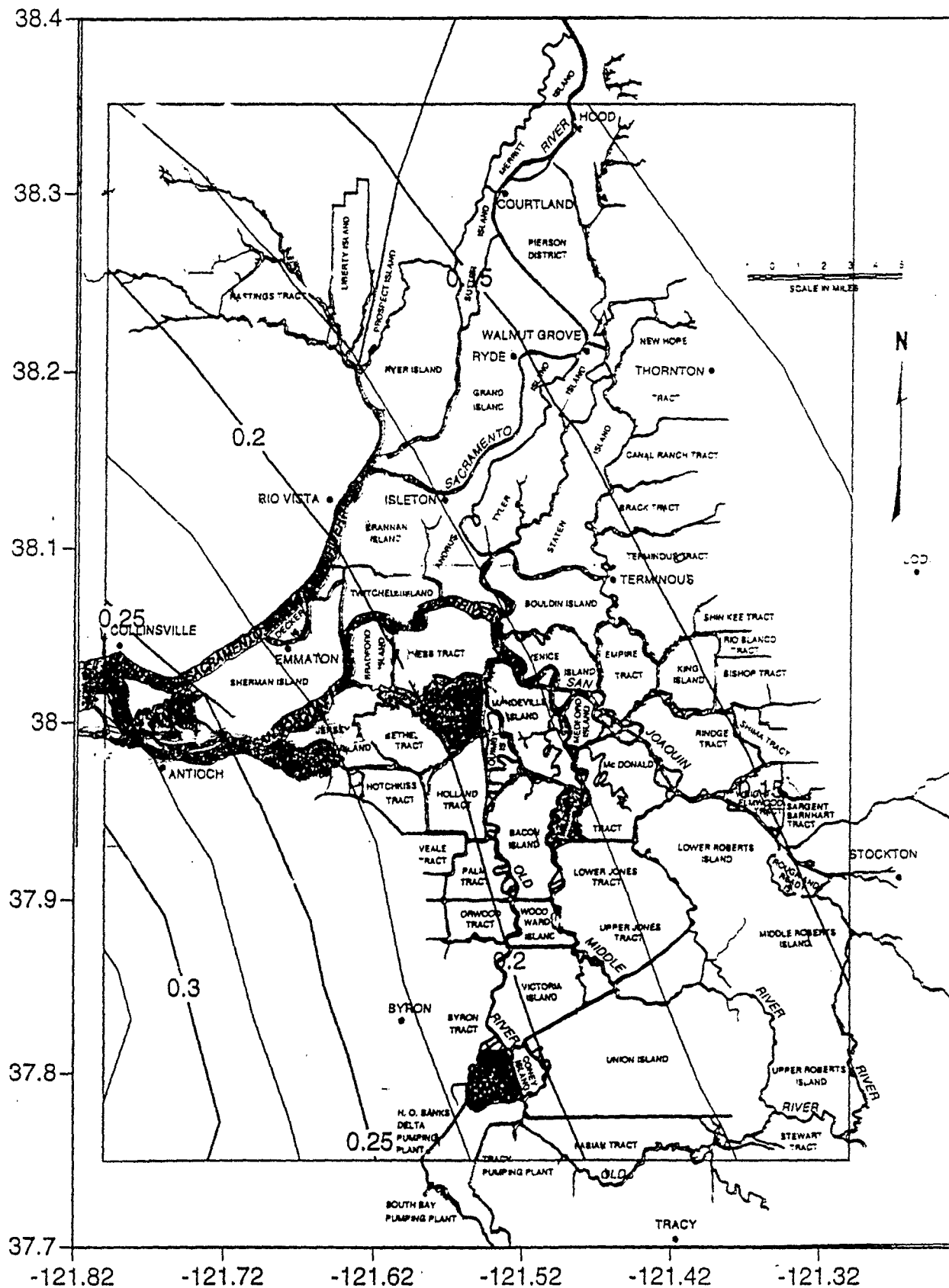Figure 9c. Contour map of seismic hazard (PGA) for soil site conditions for
a return period of 200 years.

Figure 9d. Contour map of seismic hazard (PGA) for soil site conditions for a return period of 475 years.

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Probabilistic Seismic Hazard Analysis

<u>Source Characterization</u>
    Location of Faults
    Magnitude Distribution of Earthquakes
        Maximum magnitude
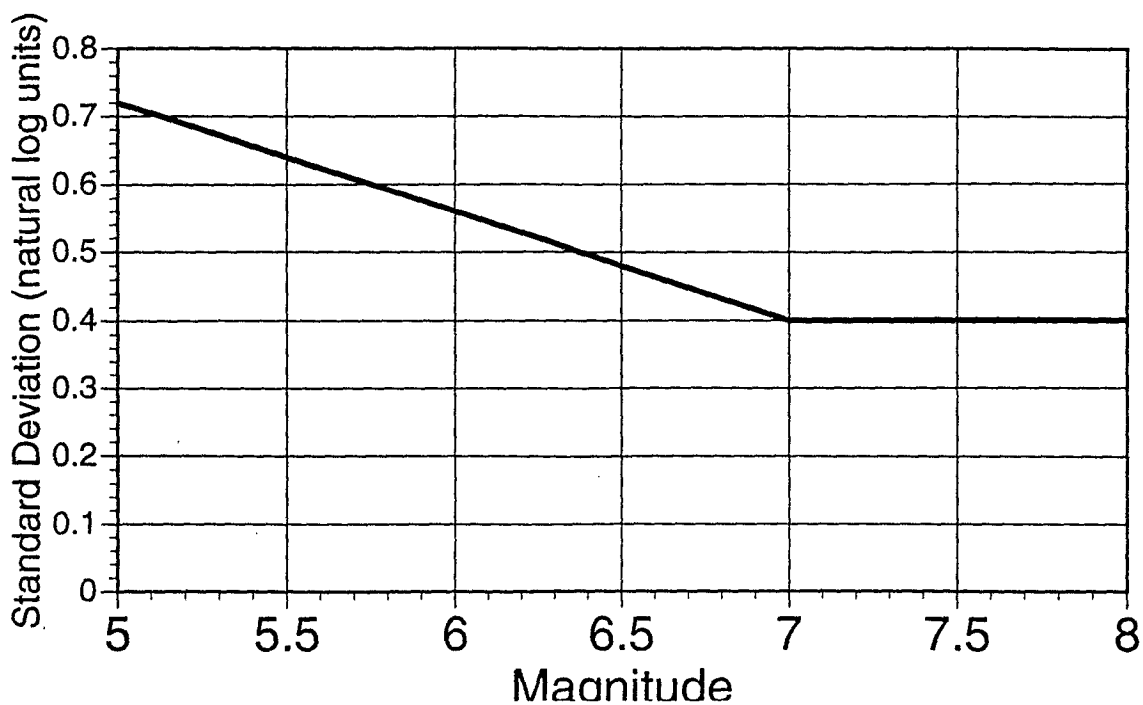   Relative number of moderate and large magnitudes
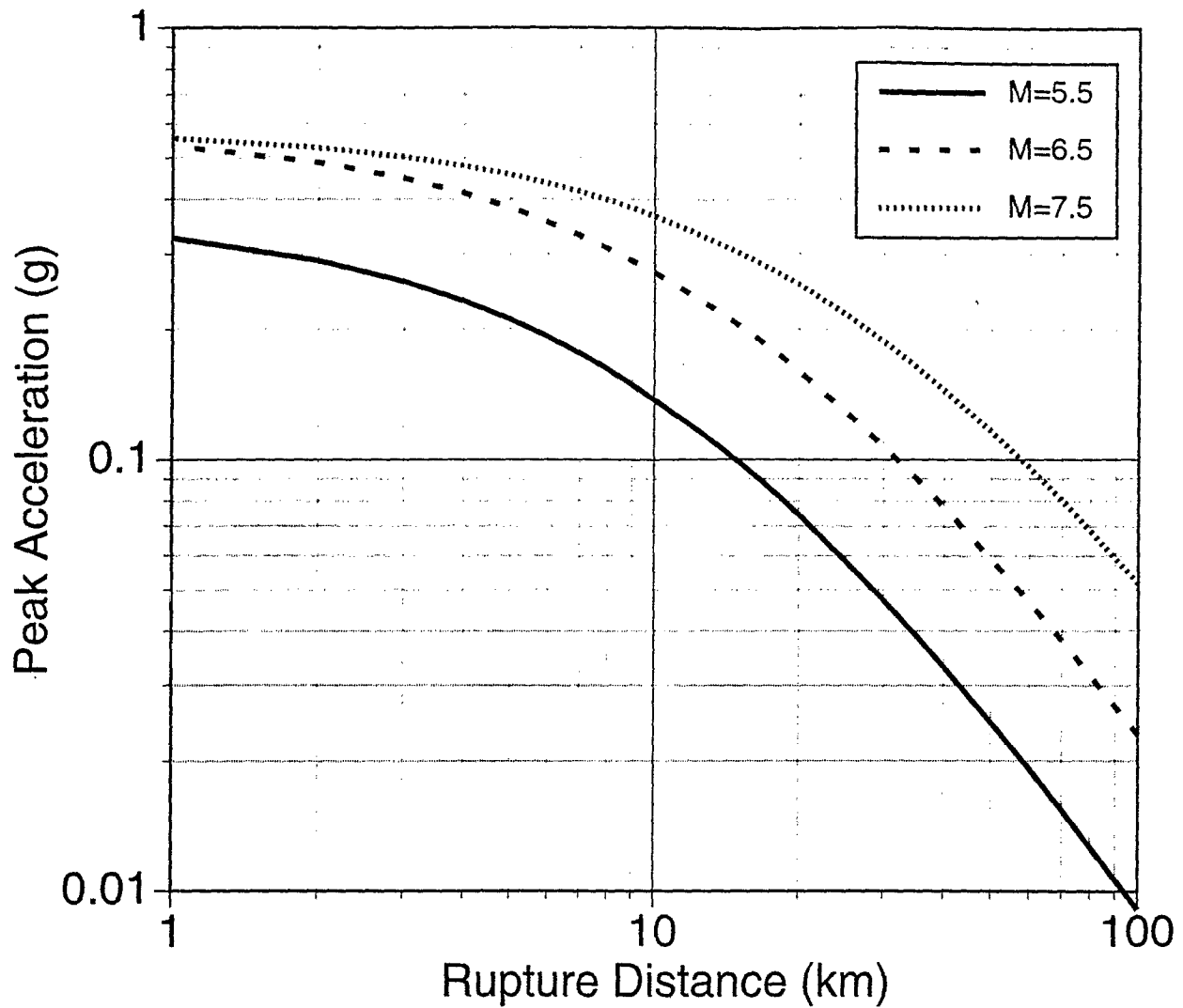   Rate of Earthquakes
        Slip-rate or historical seismicity

<u>Attenuation Relation</u>
    Strength of ground shaking for a given magnitude and distance

    Deep Soil (without peat)

Attenuation Relation for Deep Soil Sites
(Sadigh et al, 1997, Strike-Slip)
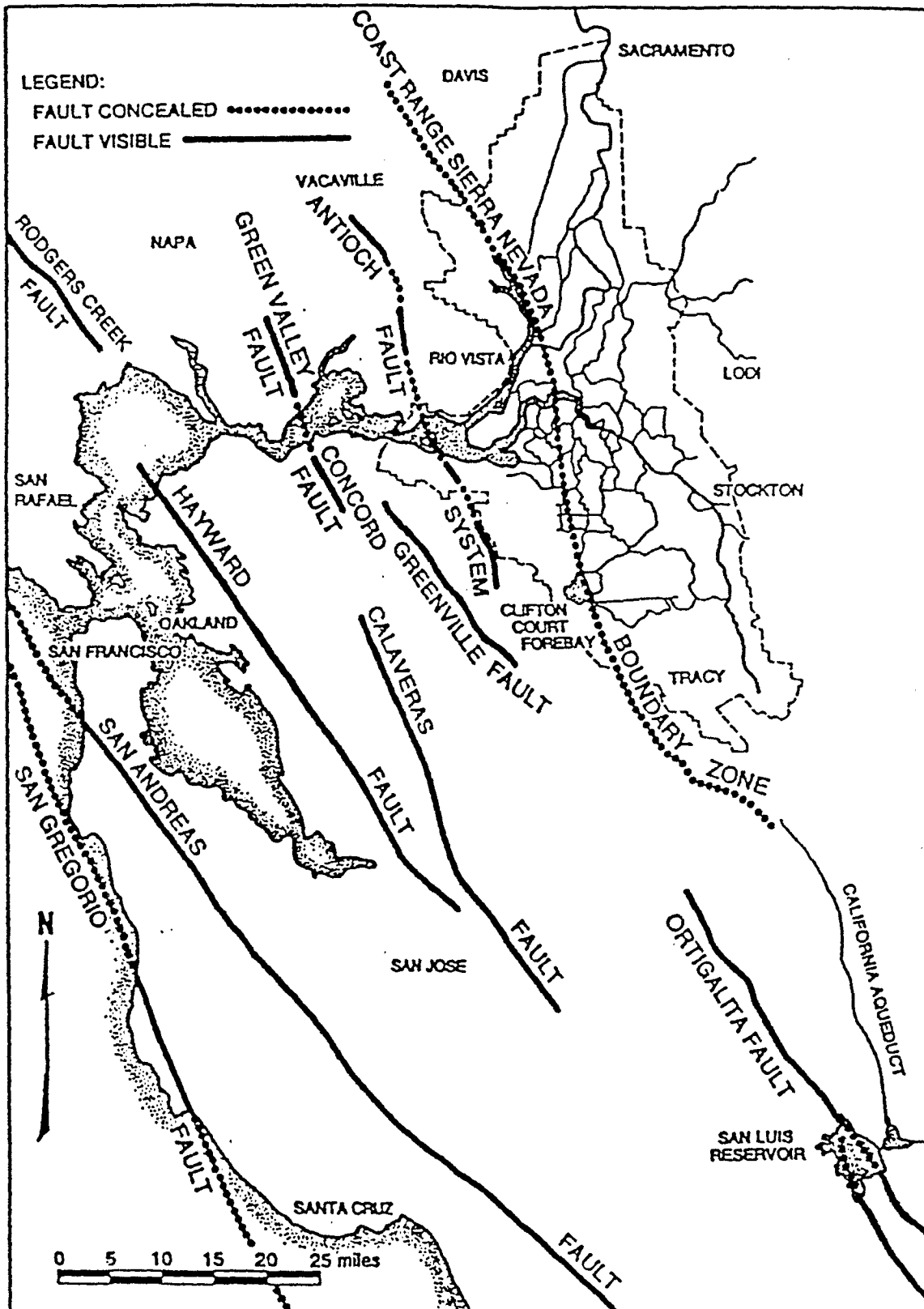
Figure 2-4:   Regional Fault Sources

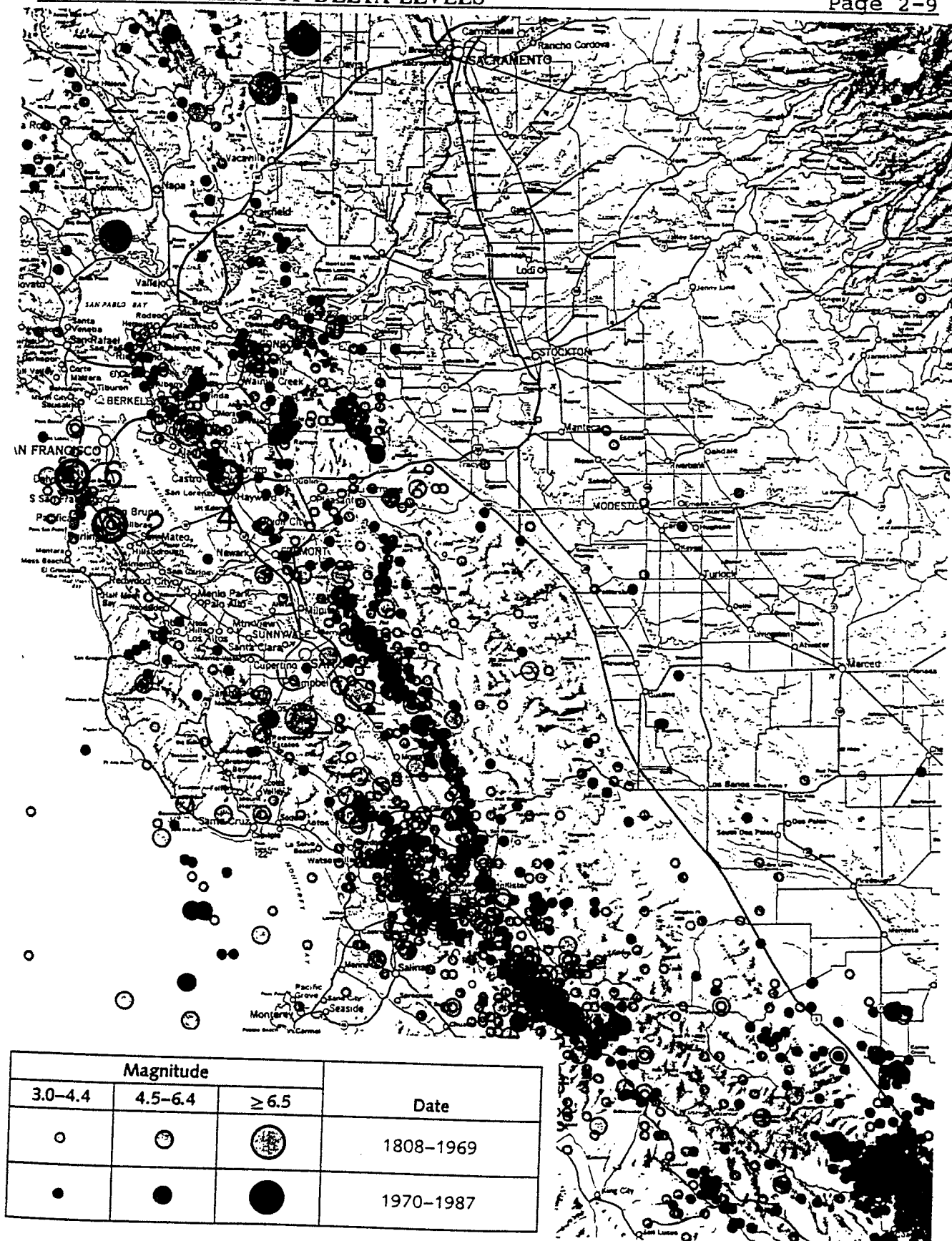| Magnitude			
3.0–4.4	4.5–6.4	≥ 6.5	Date
○	◉	⊛	1808–1969
•	●	●	1970–1987

Figure 2-5: Regional Seismicity (From USGS, 1987)